	US ATLAS HL-LHC Upgrade BASIS of ESTIMATE (BoE)	**Date of Est:** **13-May-2017** **Prepared by:** **Bing Zhou (Univ. of Michigan), Reinhard Schwienhorst (MSU)** **Docdb #:**

WBS number: 6.6.1.x	**WBS Title: Development and Production of sMDT tubes and chambers**

WBS Dictionary Definition: This WBS covers the construction and test of 27000 drift tubes (6.6.1.2) which are assembled into 48 small-tube MDT (sMDT) chambers (6.6.1.1) for the ATLAS Muon Spectrometer barrel inner station as the Level-1 trigger and precision muon tracking detector.

The deliverable for WBS 6.6.1.2 is the production of 27000 drift tubes. The deliverable for WBS 6.6.1.1 is the production of 48 sMDT chambers equipped with on-chamber gas system, the HV and RO distribution boards covered with Faraday Covers.

Estimate Type (check all that apply – see BOE Report for estimate type by activity):

_X_ Work Complete
_X_ Existing Purchase Order
___ Catalog Listing or Industrial Construction Database
___ Documented Vendor Estimate based on Drawings/ Sketches/ Specifications
_X_ Engineering Estimate based on Similar Items or Procedures
_X_ Engineering Estimate based on Analysis
_X_ Expert Opinion

Supporting Documents (including but not limited to):

Details of the Base Estimate (Explanation of the Work)

This BoE covers the production of 50% of the sMDT chambers needed for the Muon Spectrometer upgrade for HL-LHC to add the Level-1 trigger device in the barrel inner station of the Muon Spectrometer. The effort includes fabrications of facilities at Michigan State University and the University of Michigan, as well as assembly and test stations for tube and chamber productions, purchasing precision tubes and end-plugs and other components needed for construction tasks. In total, 27,000 tubes will be made and assembled into 48 chambers. The complete sMDT chambers will be shipped to CERN in early 2023 for integration with RPC and pre-commissioning prior to installation in ATLAS pit in 2024.

Labor

1) **Pre-production**: build the tube and chamber assembly and test stations and produce tubes and chambers for version 1 and version 2 to certify the tools and the precision and procedure for the construction tasks.
   a. Labor for tube pre-construction: 1.25 FTE mechanical engineer, 1.5 FTE mechanical technician from 2017 to 2019 – to set up the tube construction room, build the automatic wiring station, and the wire tension, tube leak and dark current test stations.

b. Labor for chamber pre-construction: over 2017 to 2020: total 2.35 FTE mechanical engineer, 1.37 FTE mechanical technician, 1.62 FTE electrical engineer and 1.37 FTE undergraduate student, to build the automatic gluing machine, the chamber assembly precision jigging on granite table, the precision spacer assembly station, the gas assembly and test station, and electronics (HV and RO) test station. In addition, design the mechanical structure for chamber mounting and integration with RPC as well as for alignment device installation mounts.

The needed labor FTEs are based on estimates by engineers at MSU and experience with the MDT tube and chamber constructions for Run 1 muon detector at the University of Michigan.

2) sMDT construction

a. Construction and test a total of 27000 tubes (including 10% spares), starting from April, 2020 and finishing by Sept. 2022 requires a total of 4.75 FTE mechanical technician support. Assuming on average constructing and testing 50 tubes each day. The task will need 1.0 FTE for tube assembly and 1.0 FTE for tube tests (wire tension, leak and dark current). A graduate student (uncosted) will help with the tube testing. Supervision from faculty is expected from MSU but not included in the core manpower estimation here.
b. Construction and test of total 48 sMDT chambers starting from July 2020 and finish by March 2023 requires a total of 3.0 FTE mechanical Engineer, 5.5 FTE mechanical Technician, 2.75 Electrical Engineer, and 2.75 FTE undergraduate student. All of the sMDT chambers need to be shipped to CERN by March of 2023. Assuming on average constructing and testing of one chamber in 12 days, which is largely determined by the time required to glue 8 tube layers and the spacer frame, and alignment and monitor sensors, as well as the precision measurements during the construction. Chamber service insulation and test work will be performed in parallel at different working stations for (1) gas system (3 days); (2) HV and readout distribution boards (3 days); (3) F.C. and FE mezzanine (3 days); (4) cosmic ray test (2 days), and chamber boxing for storage and shipping (1 day). Supervision from faculty and help from graduate students in physics are expected from UM, but not included in the core manpower estimation here.

The needed labor FTEs are based on experience with the MDT tube and chamber constructions for Run 1 muon detector at the University of Michigan, as well as the sMDT construction experience at MPI (Germany) for muon detector Phase I upgrade project.

<u>**Materials for pre-construction**</u>

Tubes:

a. \$40k to set up the clean room at MSU (based on engineering estimates).
b. \$18k to ship the optical table to MSU and set it up (based on experience with MDT at UM).
c. \$25k to set up tube assembly station: wiring table, clean flow-boxes, mechanical tube crimping device, wire in crimping tool, auto-wiring tension system (based on experience from UM and MPI Munich).
d. \$46k to set up testing station: tension test station, leak test station, dark current test station (based on experience from UM and MPI Munich).
e. \$25k to place the first order for tubes and tube parts (based on experience from MPI Munich)
f. \$1k for container to protect tubes for transport to UM (based on experience from UM).

Chambers:

a. $205,000 for chamber construction tooling: setup the temperature and humidity control system for the chamber assembly room, precision jigging, gluing machine, precision measurement tooling, chamber handling carts, gas manifold HV and electronics test station, chamber leak test station, shipping boxes, version 1 and version 2 construction and test (based on experience from UM).

Materials for sMDT construction

Tubes:

a. 27,000 tubes for $440k (at $16 per tube)
b. 38km wire for $46k (at $1200 per km)
c. 54,000 end plugs for $165k (at $3 per plug)
d. $25k for clean room equipment.

Core cost estimates based on experience with current production of sMDT tubes at MPI Munich. Clean room equipment estimate based on past experience with MDT construction at UM.

Chambers:

a. $401.320k for chamber material, including gas system, HV&RO HH boards, transportation carts and assembly tooling
b. $24k for chamber storage and shipping boxes
c. $16.8k glue and utilities
d. $5k for lab utilities
e. $36k for 8 shipping with air-conditioned containers to CERN.

Core cost estimates based on experience with current production of sMDT tubes at MPI Munich.

Travel

Travel from MSU to UM is included for transport of the tubes and is estimated for two people at $1650 during pre-production and $850 for one person during production.
Travel to CERN and MPI by the ME and EE is needed during the production phase to design the interface to mount chambers and to integrate RPC with sMDT, as well as to attend expert weeks. We have estimated that two week-long trips per year (each for tube and chamber construction project) will be necessary, based on our experience in constructing the MDT for the current muon detector. The estimated cost for each one-week long travel is $3000 (including ticket, hostel and per diem). (Note that the International Travel still needs to be added to P6).

Schedule

Setting up of the room and of the construction facilities starts in 2017. We plan to build version 1 tubes and a version 1 chamber in 2018 to establish the tube and chamber construction procedures and to measure the precision to finalize the construction tooling design. We will build a full-size version 2 chamber in 2019 to certify the tube- and chamber production tooling and procedures. The production readiness review is expected in early 2020.
The tube construction starts in April 2020 and finishes by September 2022. The chamber construction start in July 2020 and finishes by March 2023. The ATLAS Muon Project requires the sMDT chambers

are received at CERN in early 2023 for final integration with RPC and pre-commissioning on the surface prior to chamber installation in ATLAS pit. The sMDT installation in ATLAS will start in early 2024 (cost of sMDT and RPC integration and pre-commissioning at CERN is beyond the scope of this BOE and not included in the cost estimation).

Risk Analysis

Risk of this construction project is relatively low since all the material costs are based on real sMDT construction experience at MPI for Phase I upgrade BIS7/8 project.

Schedule Risk: Probability: Low, Impact: Low, Overall Score: Low
Potential Problems: Construction of one tube or one chamber takes longer than estimated
Mitigation: The current construction schedule is based on the time it takes for each tube or chamber at each of the stations of the construction process. Time for glue to dry cannot be changed (and is well understood), but if the number of steps turns out to be more complicated or take more time, then additional graduate or undergraduate students could be put on the taks.

Cost Risk: Probability: Low, Impact: Low, Overall Score: Low
Potential Problems: If the currency exchange rate between US Dollar and Swiss Francs changes a lot, making the purchasing of tubes and end plugs a lot more expensive.
Mitigation: The current schedule is set up to make four purchases of materials. If the exchange rate changes a lot over that duration, then the purchases of materials can be spaced differently, for example purchasing additional tubes and plugs earlier.

Technical/Scope Risk: Probability: Low, Impact: Low, Overall Score: Low
Potential Problems: The tubes or chambers don't pass the technical requirements.
Mitigation: The tubes and chambers currently produced at MPI Munich pass all of the requirements, and the fabrication procedures at MSU and UM will be reviewed in 2020. Any issues will be fixed at that time.

M&S Contingency Rules Applied

Rule 5: 25% based on our past experience with the present MDT construction at Michigan. One major factor will be the currency exchange rate fluctuations between US Dollar and Swiss Francs in purchasing of precision Al tubes and end-plugs.

Labor Contingency Rules Applied

Rule 3: 30% contingency on labor for the sMDT tube and chamber construction.

Comments:

UM built 32,000 long drift tubes and 80 large MDT chambers for the current ATLAS Muon Spectrometer. The quality of the MDT chambers built at Michigan is high and they are operating reliably since Run 1 and now in Run 2. Moreover, UM kept the construction rooms and experienced engineers (Curtis Weavedyke, Tiesheng Dai and Bob Ball), and physicists (Bing Zhou, Dan Levin, Shawn McKee, Claudio Ferretti and Ed Diehl). In addition, we have two additional faculty members, Dan Adimei and Jianming Qian, who expect to participate in the sMDT project. Professors Tom Schwarz and Junjie Zhu have been heavily involved in Phase I and Phase II upgrades for front-end electronics projects. Michigan State University (MSU) has joined the sMDT construction tasks. MSU has identified the space for tube construction and storage and handling in its HEP high bay area. MSU also has experience in muon tube and chamber construction from the SSC. The engineer knowledgeable about that project is also active today. MSU engineers and technicians have also been active in other ATLAS construction projects, including large tile calorimeter modules and tile calorimeter electronics. Brock has a long history of guiding construction projects, most recently for an ATLAS Phase-0 trigger electronics upgrade project. Schwienhorst is L3 manager for an ATLAS Phase-1 trigger upgrade project.

Figure 1 shows the tube and chamber structure (currently built at MPI for Phase I BIS7-8). US team will contribute in design and construction of BIS1-6 chambers, mechanical supporting and integration with RPC chambers. It is very challenging to design the chamber and supporting structure to fit in very limited space in the inner station area and to meet high precision requirements for muon momentum measurement and for Level-1 muon trigger at the high luminosity environment.